

AFFTC-PA-11014



# LESSONS LEARNED WHILE MEASURING FUEL SYSTEM DIFFERENTIAL PRESSURE

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14. ABSTRACT  A recent aircraft project required the measurement of differential pressures across a fuel filter during engine operation. Early testing showed intermittent noise in the system. Additionally, transducers were failing. Attempts to troubleshoot the problem led to the discovery of unexpected large pressure transients within the fuel system which were causing the "noise" and damaging the transducers. Attempts were made, with some success, to gather the data without extensively modifying the existing system. This presentation provides a brief review of what was done and what was learned from this program.					
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# Air Force Flight Test Center



*War-Winning Capabilities ... On Time, On Cost*

## Lessons learned while measuring fuel system differential pressure

10 May 2011



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# Overview



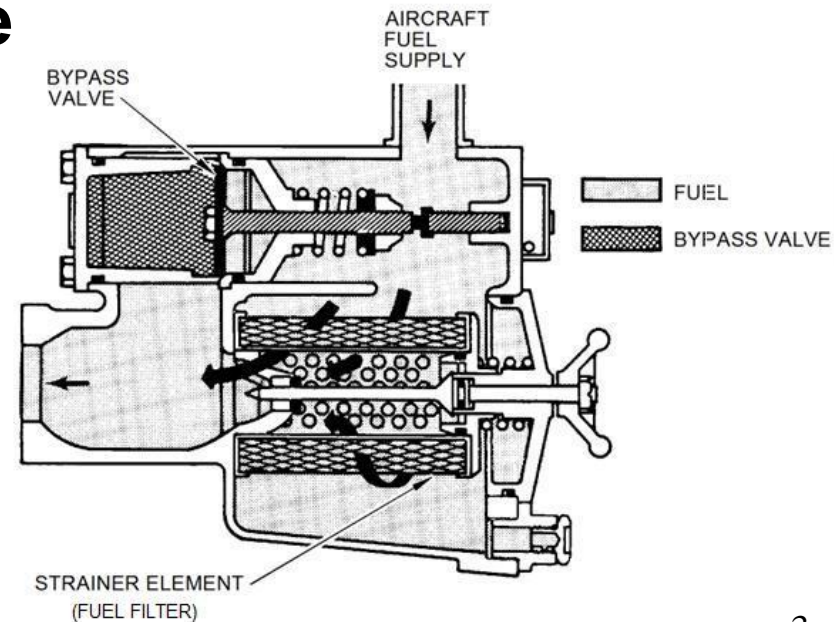
- **Requirement**
- **Method**
- **Early problems**
- **Resolution**
- **Results**
- **Lessons learned**



# Program Requirement



- **Demonstrate fuel pressure characteristics**
  - Ice buildup on strainer
  - In flight
- **Normally: 0.2 psid**
  - Clean filter
- **Strainer has bypass valve**
  - Opens when filter clogs
  - Opens at ~ 1 psid
  - Full flow at 2.1 psid
    - Blocked strainer





# Approaches (1)



- **Differential Pressure across strainer**
  - Engines already instrumented
- **Video of strainer in housing**
  - Intrusion of camera or borescope in fuel
  - Extensive modification to strainer housing
  - Would ice be obvious?
    - Require further lab testing
  - Time



# Approaches (2)



- **Use Hall Effect Sensor on bypass valve**
  - **Require modification to strainer housing**
  - **Provide actual bypass valve position**
- **Seal bypass valve**
  - **Method used during lab testing**
  - **Minor modification to strainer housing**
  - **Potential engine flameout**



# Design

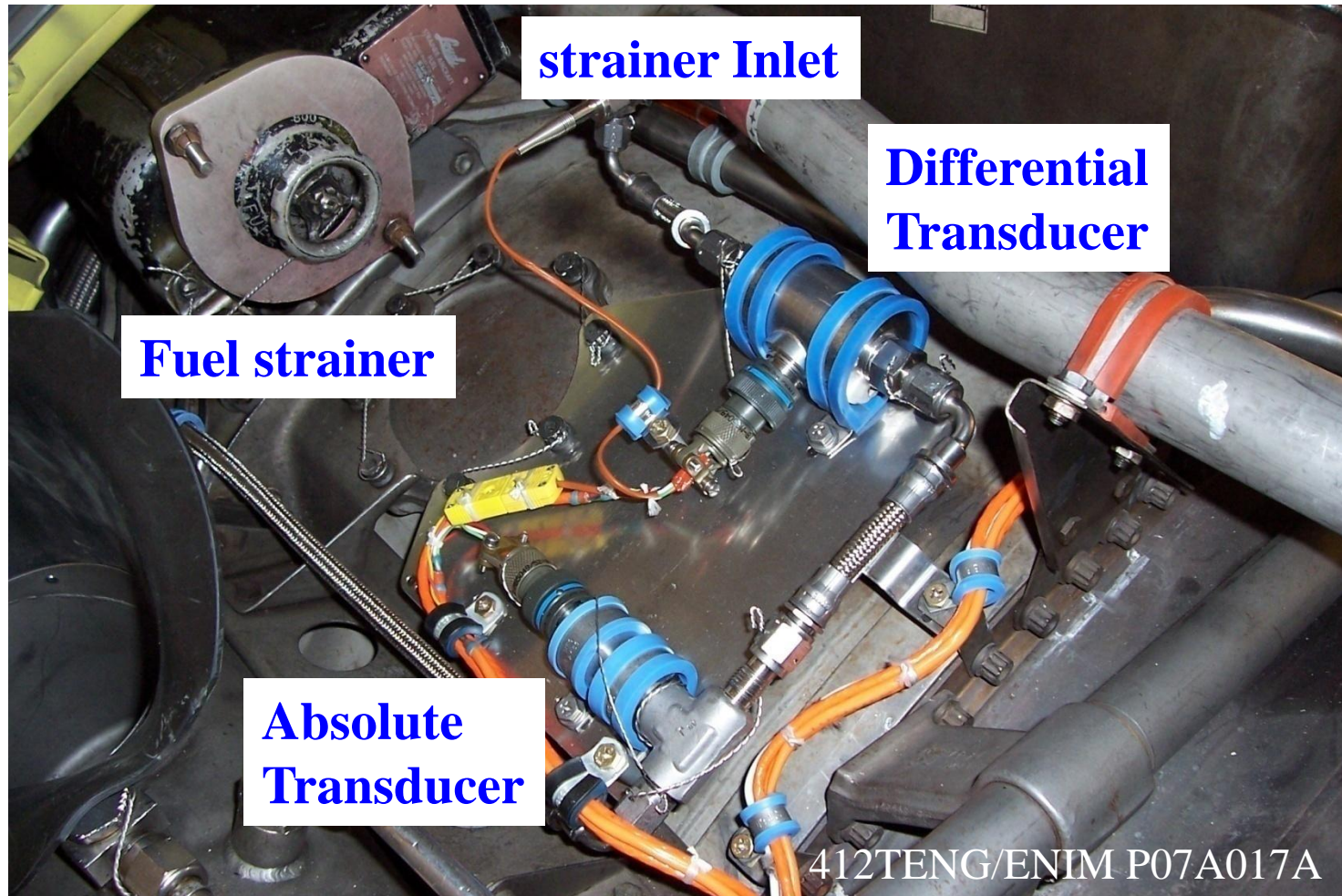


- **Measure differential pressure across strainer**
  - **+/- 15psid transducer**
  - **Amplified, 5V output**
- **Absolute pressure measured on strainer output**
  - **100psia transducer**
  - **Passive bridge, 100mV output**
- **Used transducers on hand**





# Layout

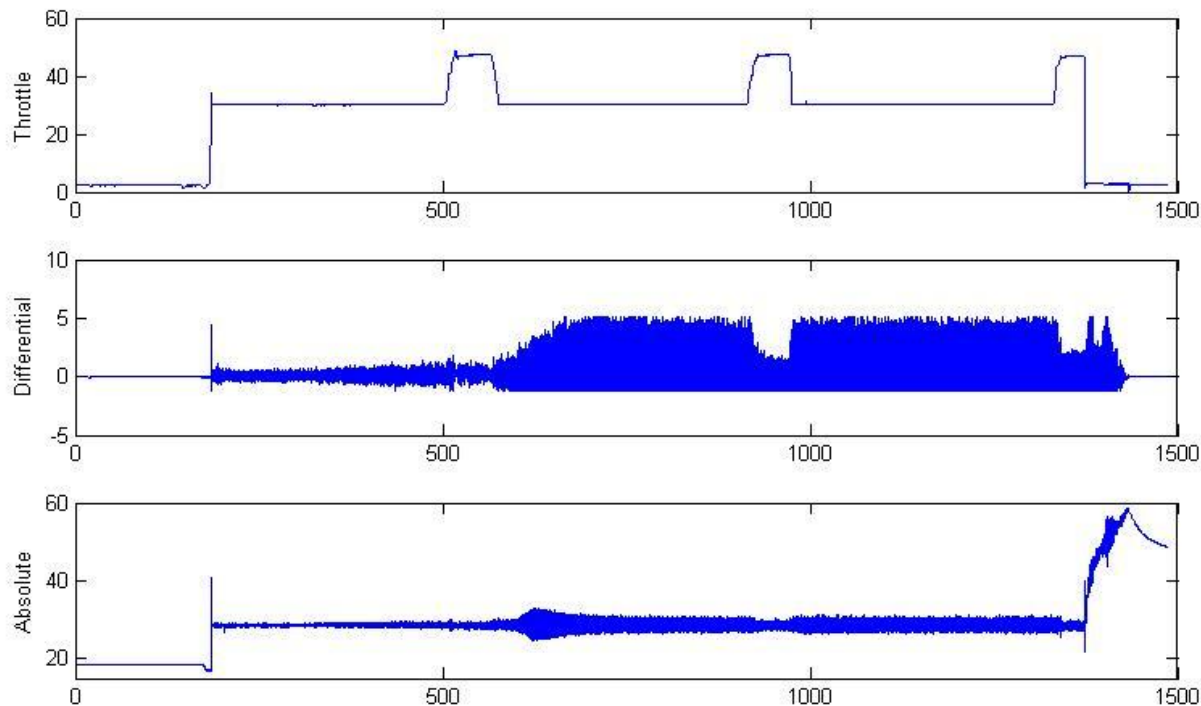




# Initial Testing



- Data looked good during acceptance testing
- Later ground testing “noisy”
- Replaced transducers to combat “noise”





# Troubleshooting Difficulties



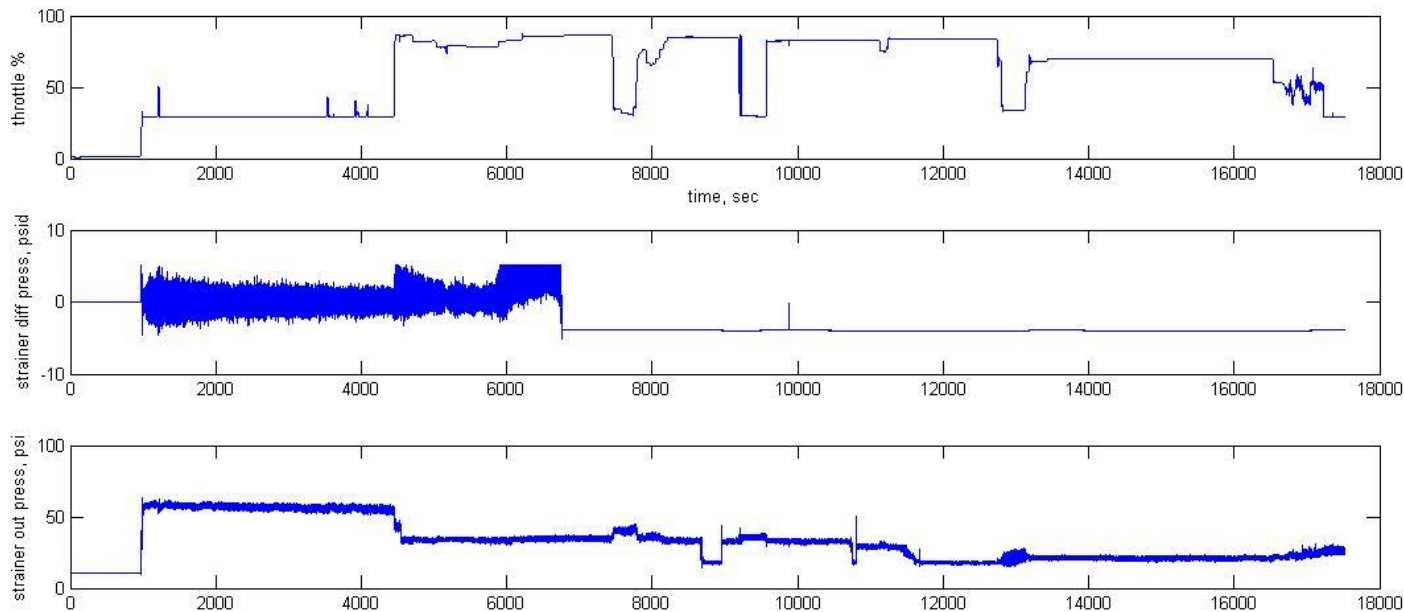
- **Priority to test**
  - Plane available for limited time
  - Try quick simple fixes
- **Access to aircraft**
  - Other programs on aircraft
- **Slow update rate from onboard display**
  - Hard to quantify noise levels
- **Data access**
- **Fuel system knowledge**



# First Flight



- **Baseline flight**
  - New transducer
  - Day prior ground test good





# What To Do?



- **Noise or Data?**
- **Quick fixes**
- **Add “dummy” transducer**
- **Perform autopsy on failed transducer**
- **Plan for alternatives**



# Noise or Data?



- **Indications point to fluctuations being data**
  - **Hard transducer failure**
  - **No significant noise on other channels**
  - **Noise levels change with throttle change**
  - **Noise voltage levels**
    - **Absolute transducer-passive, 5mv “noise” seen**
    - **Differential transducer-active, 2v “noise” seen**
    - **Similar EU values between the two**
- **Lab tests showed no pressure fluctuations**
  - **Flight representative?**



# Quick Fixes



- **Replaced transducers**
  - **Passive vs. active**
    - **DAS-Transducer coupling?**
  - **Little or no effect**
- **Altered grounding of transducer and DAS**
  - **Little or no effect**
- **Instrument for temperature**
  - **Not a factor,  $< 50^{\circ}\text{C}$**



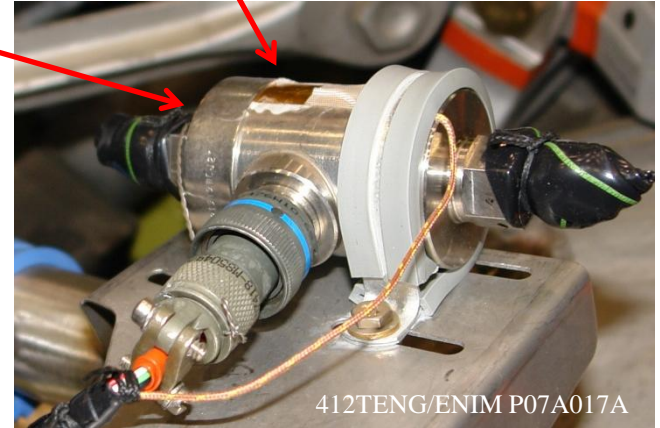


# Dummy Transducer

Thermocouple

Ground Strap

- **“Dummy” transducer**
  - Installed on another engine
    - Previously instrumented
    - Transducer removed
  - Not connected to fuel Line



- **Also noisy**
  - Coincidence?
  - Bad transducer?
  - Noisy ground?
  - Noise Level

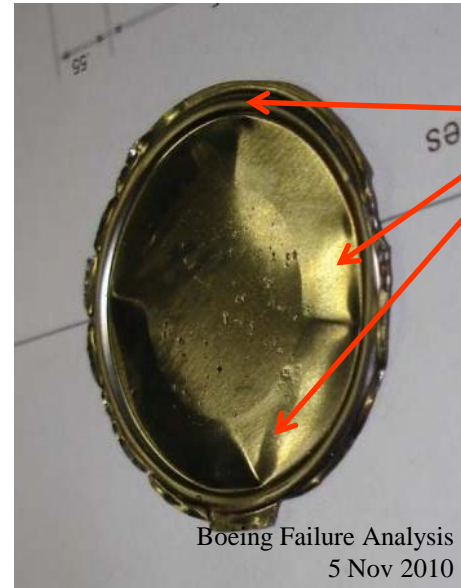




# Transducer Autopsy



- **Electronics still good**
  - Amplified output at -1.0V
  - Zero adjustment worked
    - Could not be brought to zero
  - Not responsive to pressure
- **Diaphragm distorted**
- **Bridge de-bonded & broken**
- **Causes**
  - Overpressure
  - Severe dynamic fluctuations



Damaged  
Areas



# Cause



- **Fuel pump pressure noise**
  - Cavitation
  - Surge
- **Valves**
  - Water Hammer effect
- **Affect each side of transducer differently**
  - Strainer
  - Different paths
  - Air pockets



# Fuel system



- **Investigate fuel system**
  - **Boost pumps**
    - Low pressure
    - Normally fuel comes from boost pumps
  - **Auxiliary pumps**
    - High pressure
    - Test fuel comes from auxiliary pumps
    - Significant pressure fluctuations observed
  - **Switching pumps often caused “noise”**
    - Accompanied by pressure spikes
      - 100+psi
    - Became obvious later



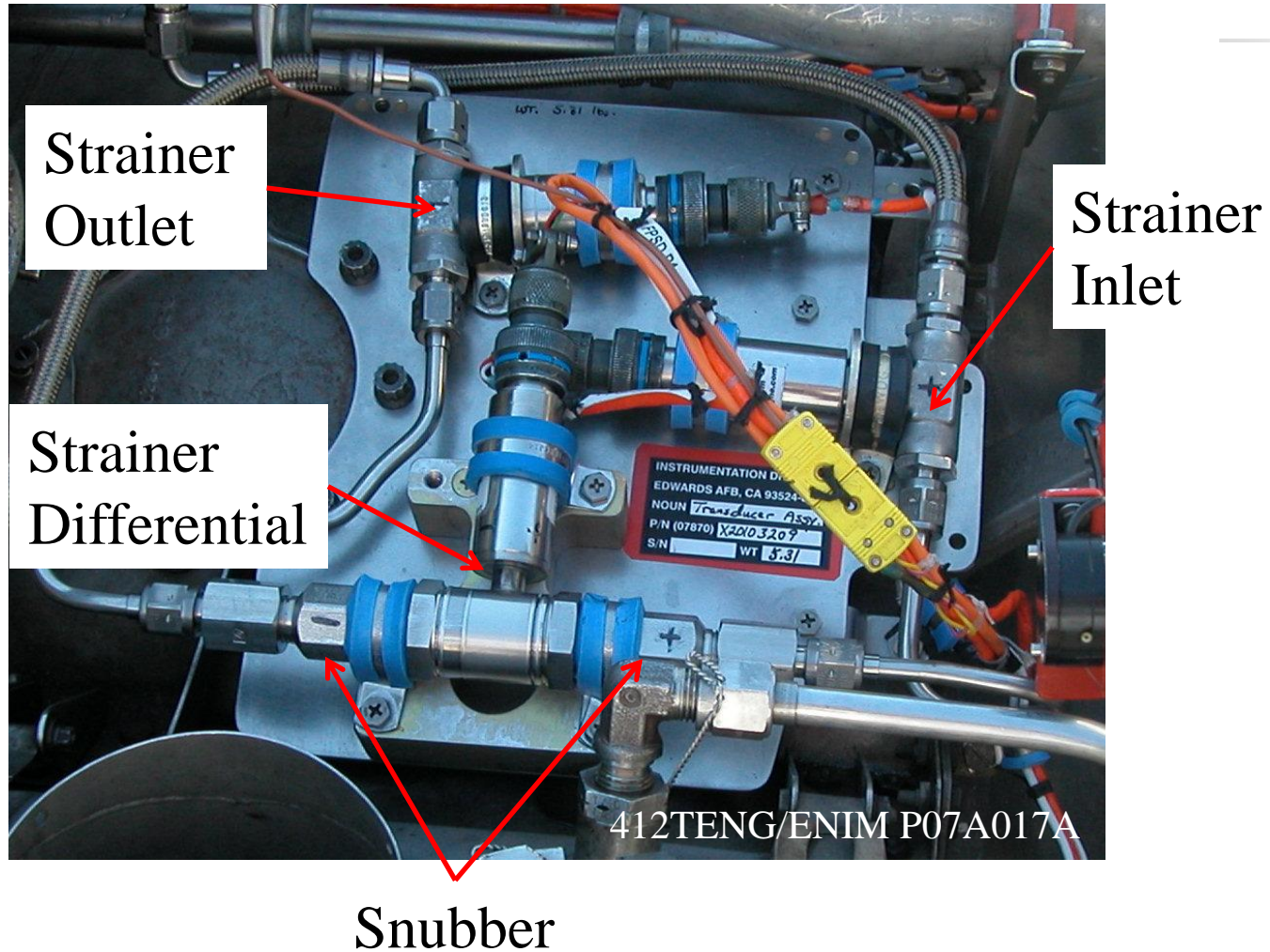
# New plan



- **Add redundancy**
  - **Use two absolute pressure transducers**
    - **Input and output of strainer**
    - **Lower fidelity**
    - **Good results when filtered**
- **Alternative Instrumentation ruled out**
  - **Hall effect sensor**
  - **Seal bypass valve shut**
- **Add pressure snubbers**
  - **Porous membrane to dampen transients**
  - **Applied to differential transducer only**

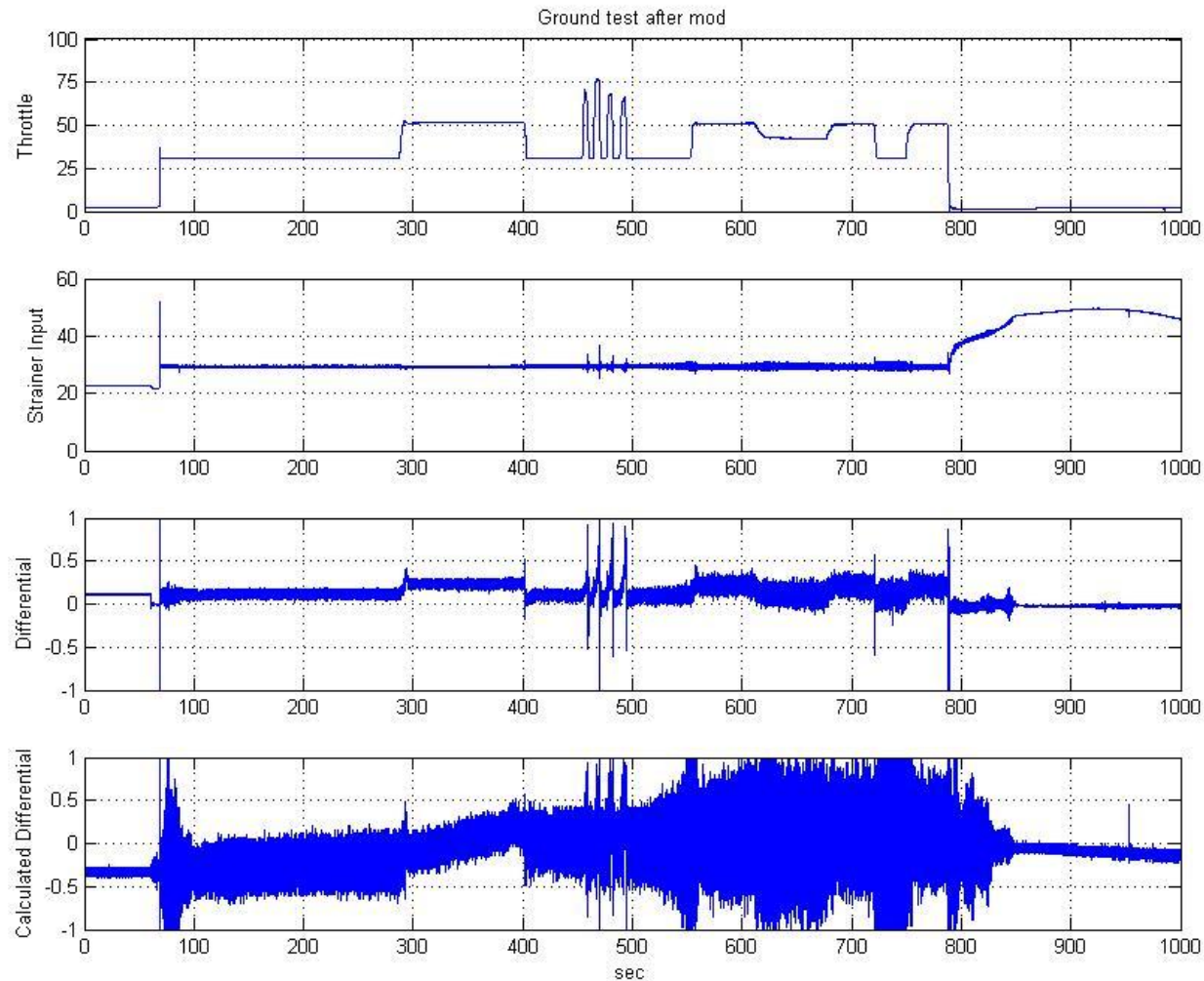


# Layout





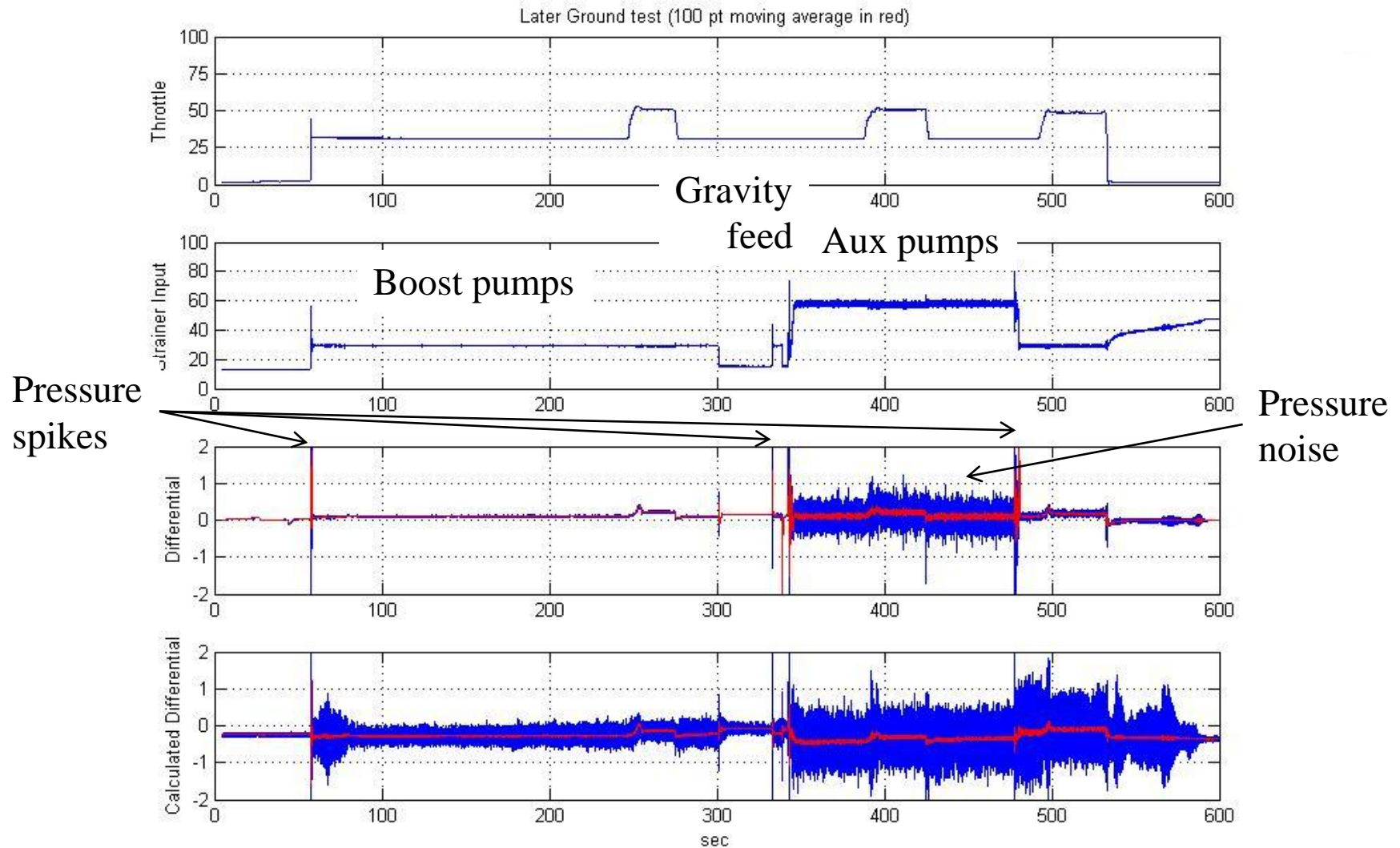
# Initial Ground Test





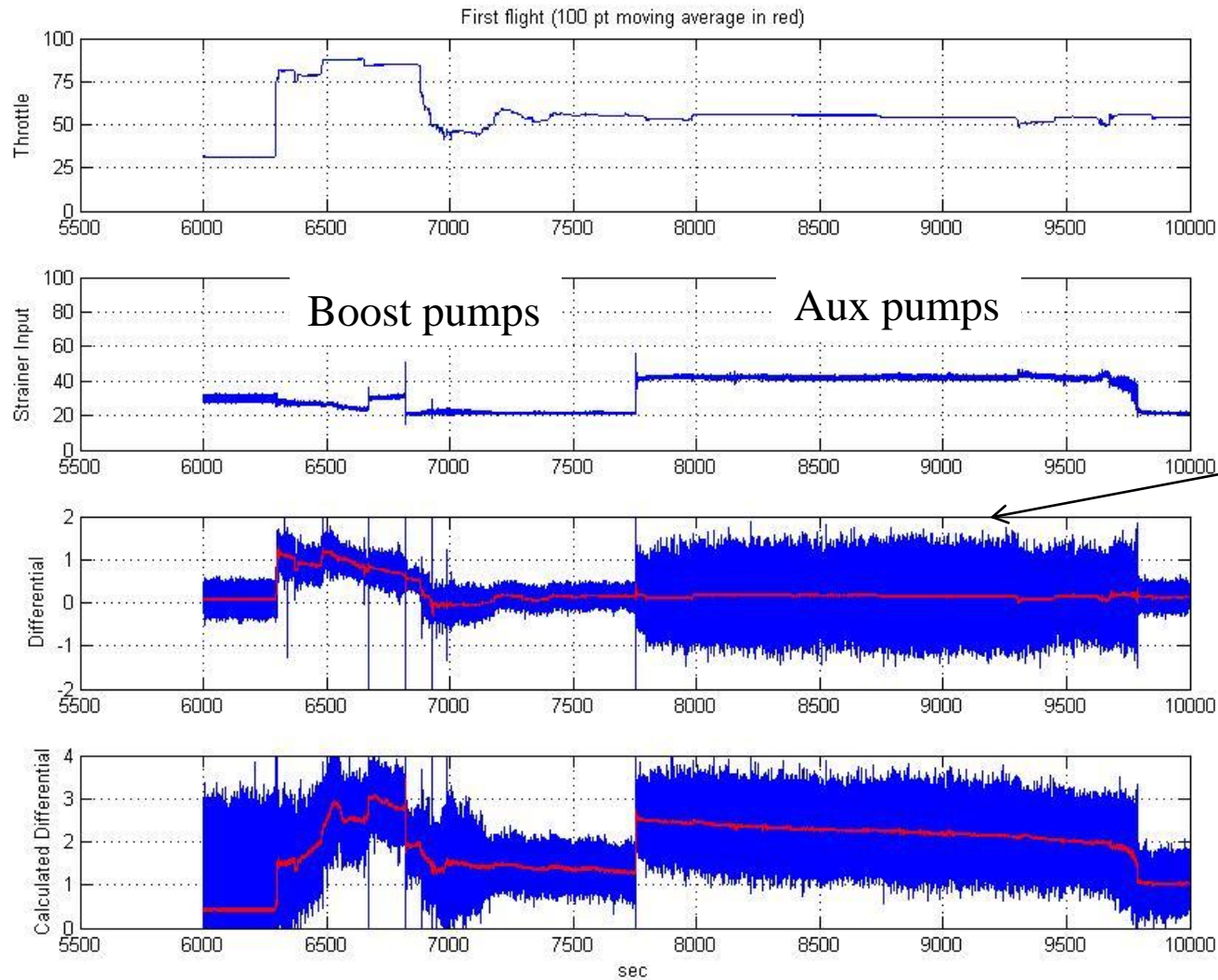


# Later Ground Test





# First Flight



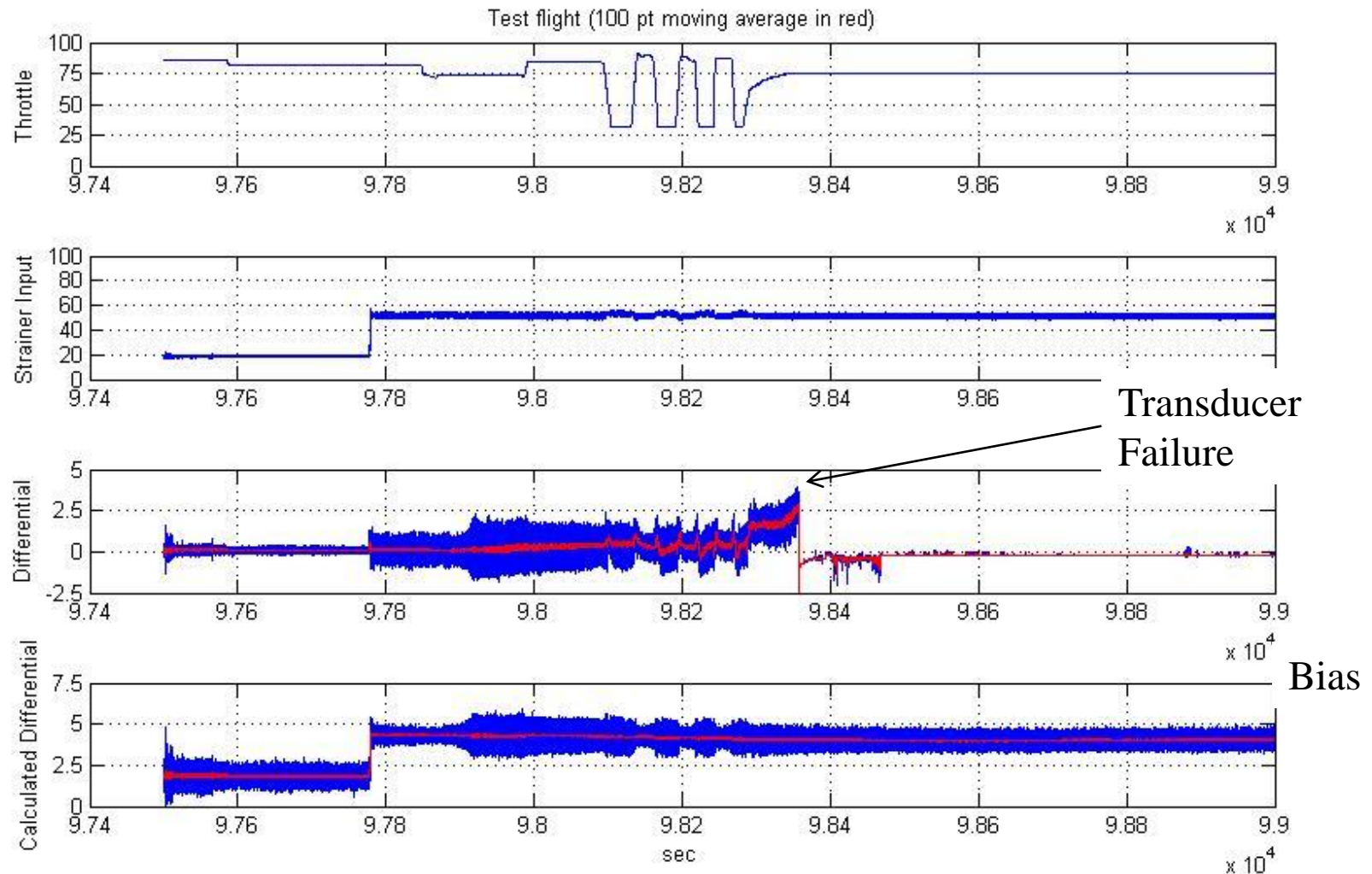
Pressure  
noise

Drift  
and  
Bias





# Last flight





# Lessons Learned (1)



- **Easy to look for problems with instrumentation**
  - Spent too much time looking for “noise”
- **Coincidence wreaks havoc**
  - Fuel pumps
  - Dummy transducer
- **Know the system**
  - Did not expect high transients or fluctuations
  - Did not understand fuel pump differences



# Lessons Learned (2)



- **Look at the data**
  - Onboard display limited
  - Slow turnaround of data
  - System characteristics in data
- **Fuel systems may exhibit transient pressures**
  - Valves and pumps
  - 100+psia and 30psid transients
- **Redundancy is good**
  - Second absolute transducer saved last flight
- **Lab test may not represent flight**
  - No transients observed in lab



# Summary



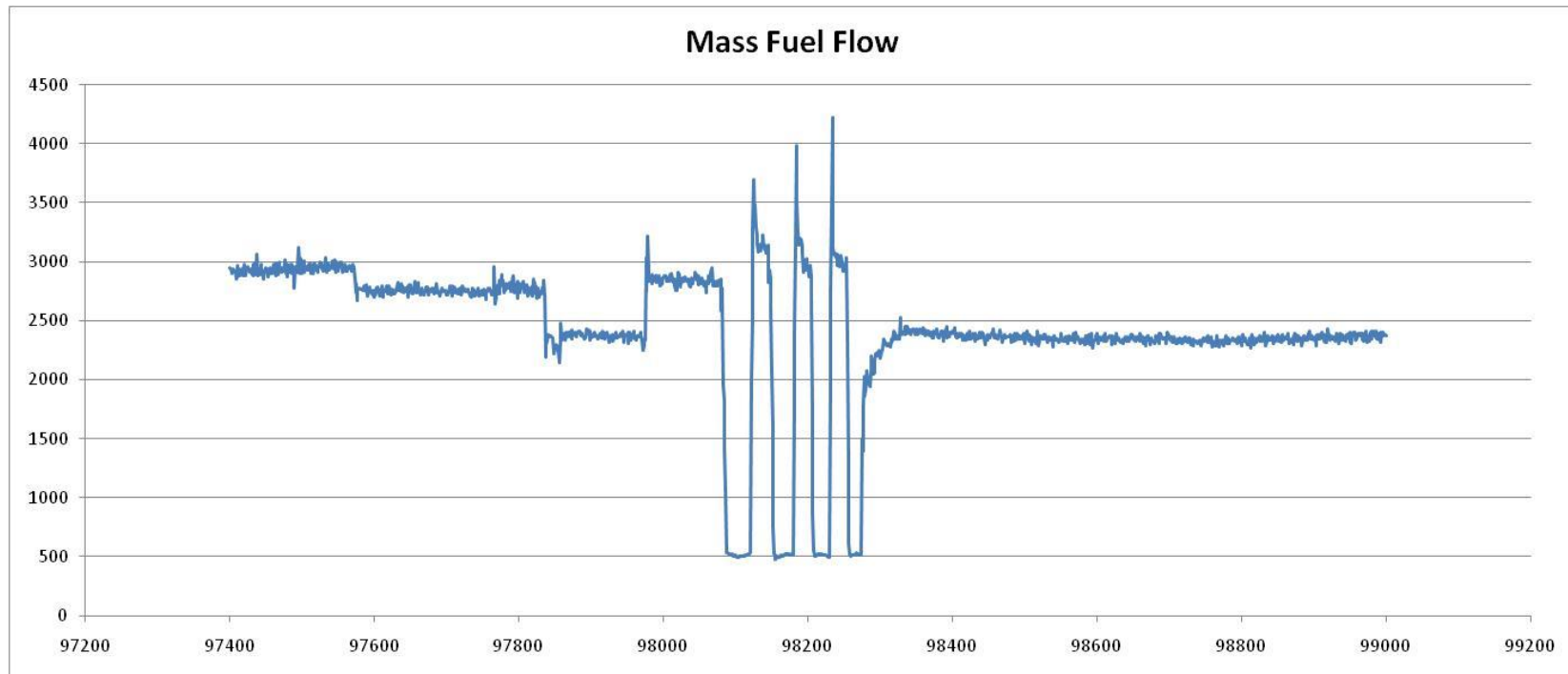
Questions?



# Back Up Slides

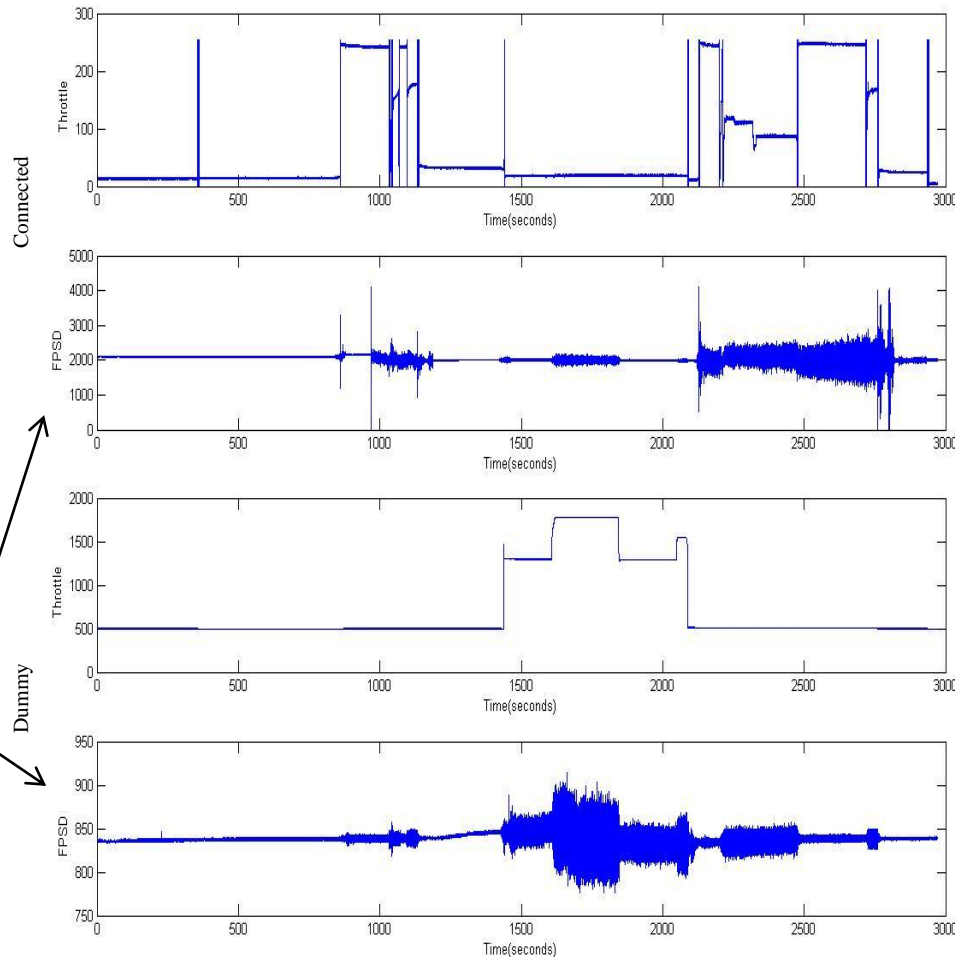


# Last flight





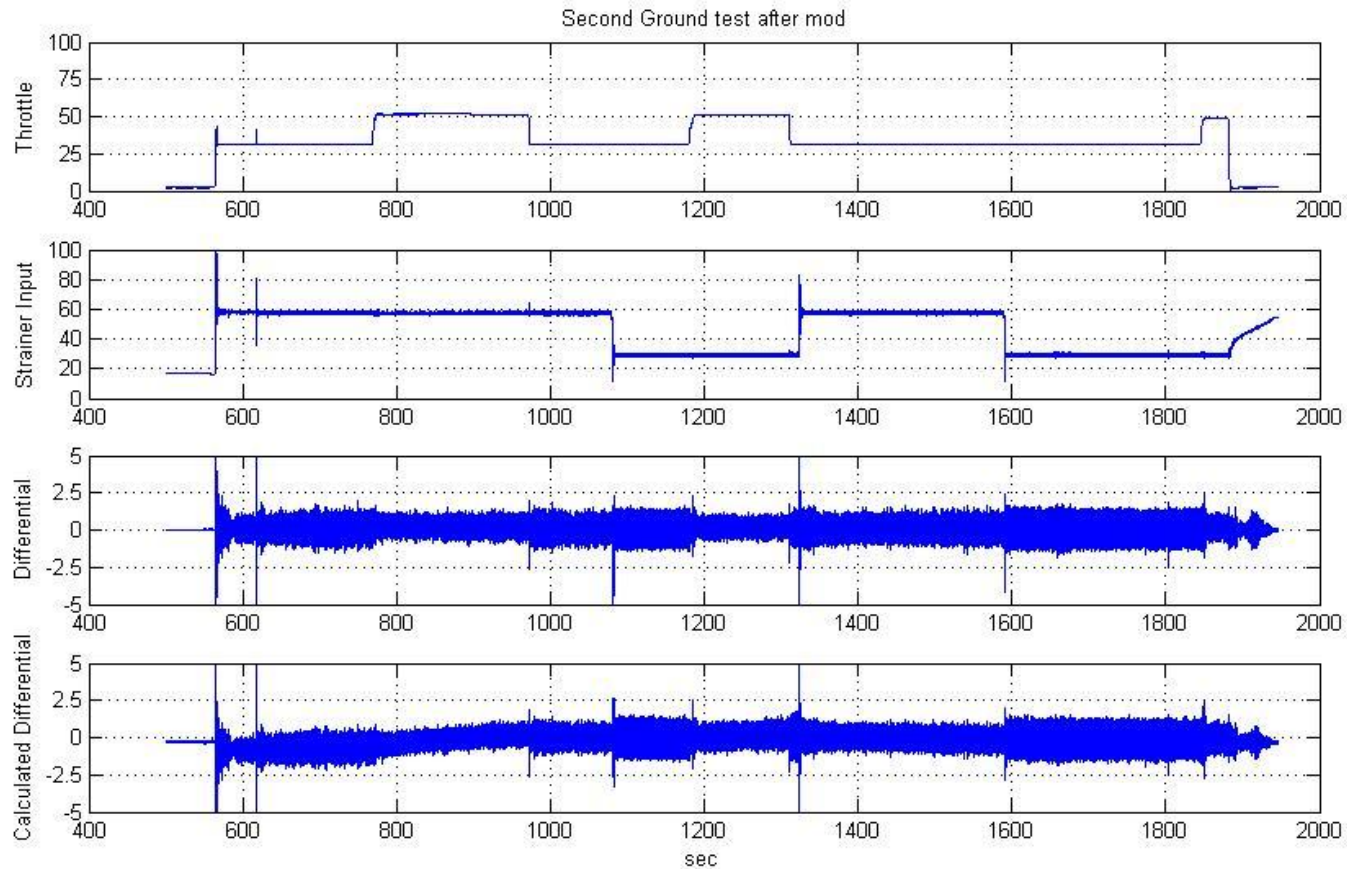
# Dummy Noise



- Reacting to throttle
- Lower level
- Scale
- Coincidence?
- Bad transducer?
- Noisy ground?



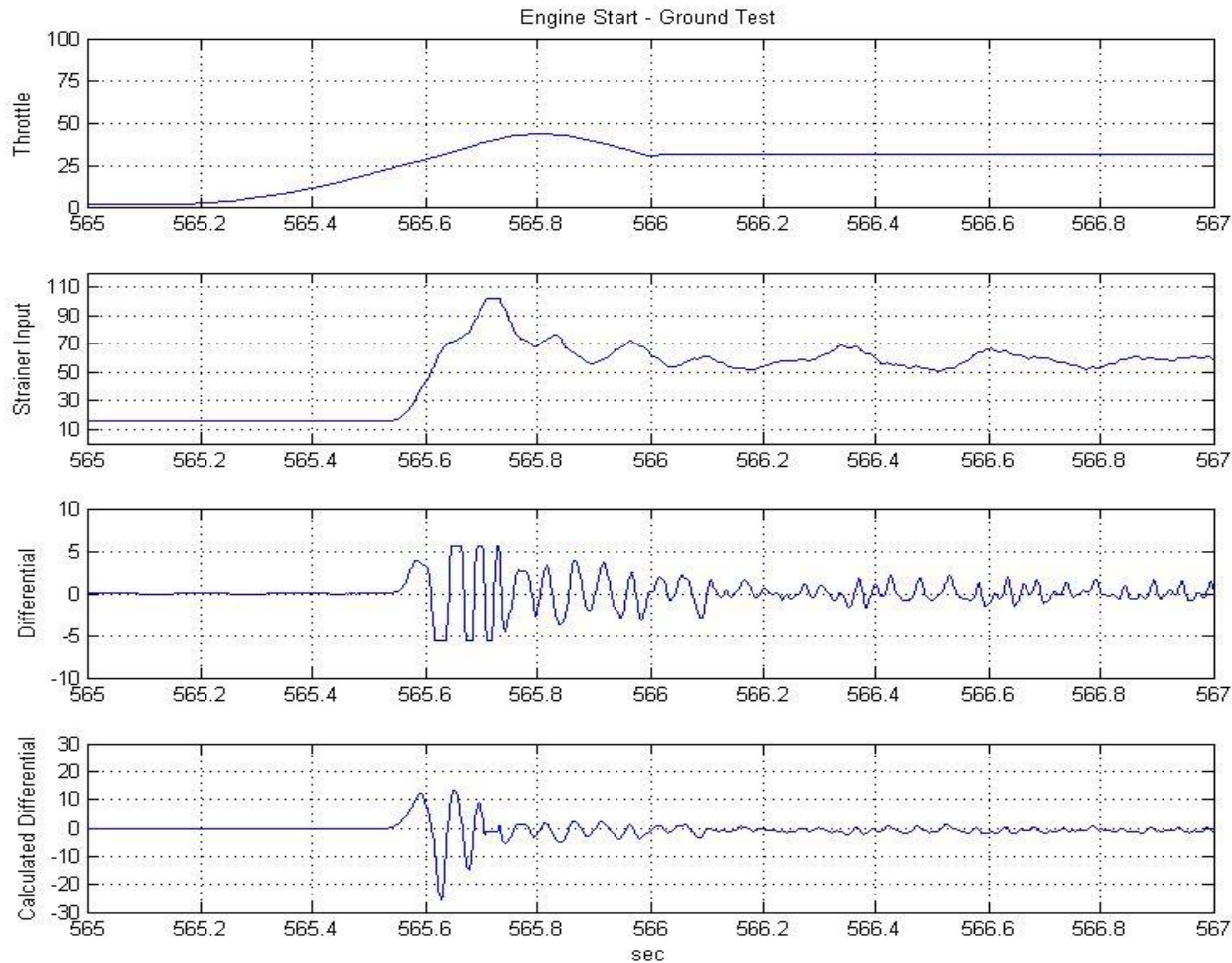
# Second Ground Test





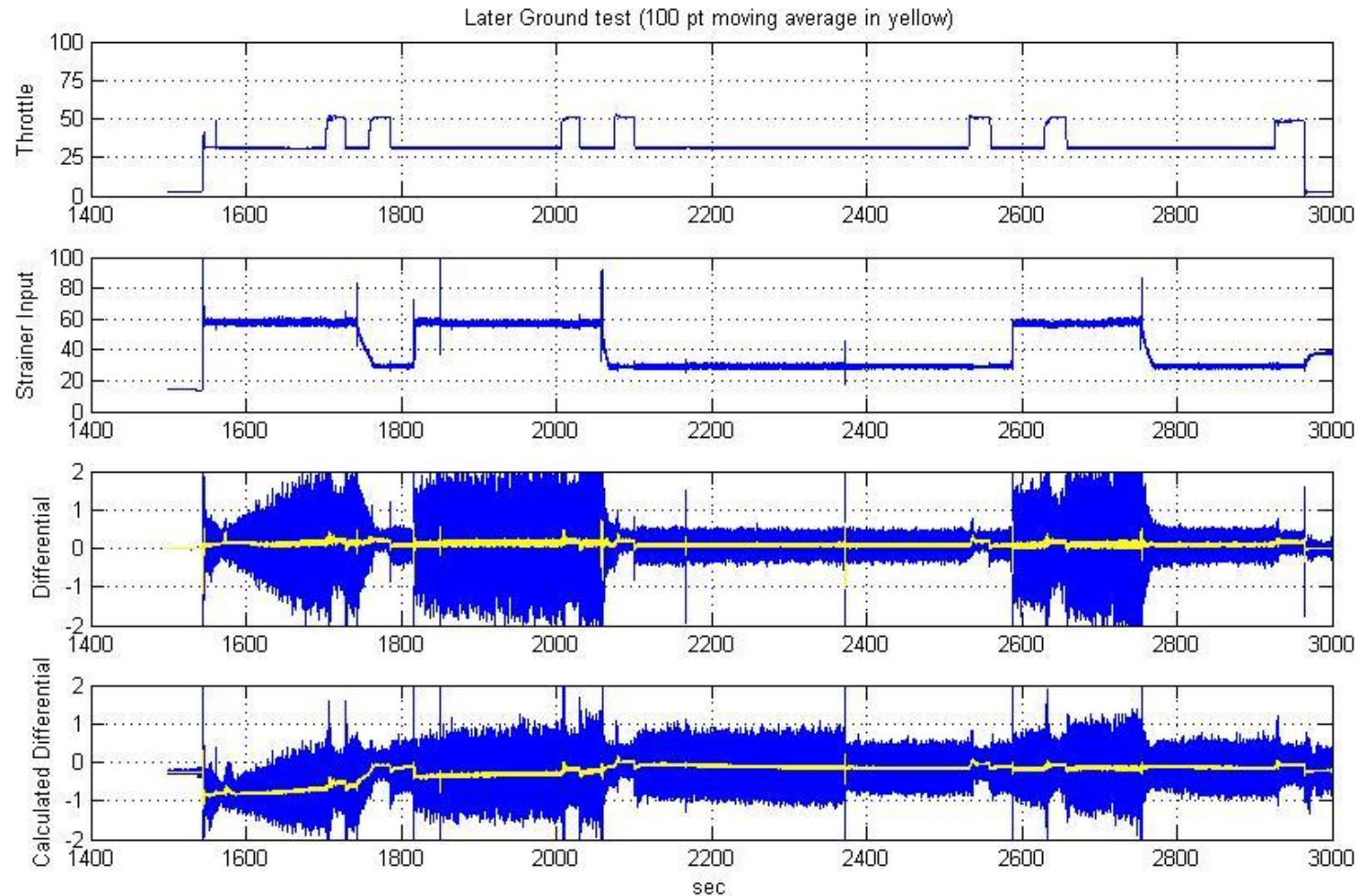


# Engine Start Transients





# Later Ground Test





# Flight 2



- Flight test after modification
  - Data filtered
  - Start of test

